

Atmospheric considerations for CTA site search using global models

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Abstract. The Cherenkov Telescope Array (CTA) will be the next high-energy gamma-ray observatory. Selection of the sites, one in each hemisphere, is not obvious since several factors have to be taken into account. Among them, and probably the most crucial, are the atmospheric conditions. Indeed, CTA will use the atmosphere as a giant calorimeter, i.e. as part of the detector. The Southern Hemisphere presents mainly four candidate sites: one in Namibia, one in Chile and two in Argentina. Using atmospheric tools already validated in other air shower experiments, the purpose of this work is to complete studies aiming to choose the site with the best quality for the atmosphere. Three strong requirements are checked: the cloud cover and the frequency of clear skies, the wind speed and the backward trajectories of air masses travelling above the sites and directly linked to the aerosol concentrations. It was found, that the Namibian site is favoured, and one site in Argentina is clearly not suited. Atmospheric measurements at these sites will be performed in the coming months and will help with the selection of a CTA site.

The ground-based observation of high-energetic photons uses the atmosphere as a giant calorimeter. Photons interact in the upper atmosphere with molecules in the air and produce air showers, cascades of billions of secondary charged particles. These particles travel through the air faster than the speed of light in the medium, creating Cherenkov light in the process. The amount of Cherenkov light emitted per metre can be used to perform a calorimetric measurement of the shower energy. The detectors of the Cherenkov Telescope Array (CTA) will be spaced several metres apart on an area of a few square kilometres to measure the same air shower from different angles [1]. This enables a better angular reconstruction of the shower axis and improves the estimate of the shower energy. To reconstruct the energy accurately, the atmospheric conditions have to be known very well. The Cherenkov light yield depends on the refractive index, which in turn depends on temperature and pressure. Also, the photons are attenuated on their way to the detector by Rayleigh and aerosol scattering.

Four possible locations for the CTA site on the Southern Hemisphere are evaluated. The site on the African continent is located on the Khomas Highland Plateau in the Khomas region of Namibia. The coordinates are 23° S, 16° E. This point is close to the site of the H.E.S.S. [2] gamma ray observatory. Three sites are evaluated in South America, La Silla in the Coquimbo region of Chile (29° S, 70° W, close to the La Silla Observatory), El Leoncito National Park in the San Juan province of Argentina (32° S, 69° W, close to the Leoncito Astronomical Complex) and San Antonio de Los Cobres in the Salta province of Argentina (24° S, 66° W).

1. The Global Data Assimilation System and its application to the candidate sites

Height-dependent profiles of the state variables of the atmosphere can be measured by weather balloons. An extensive balloon program is very costly and requires trained personnel and special equipment. Balloon launches are performed at several places around the world on a regular basis, mostly on airports to monitor the local conditions for air travel. These data are available online and can be used in the reconstruction of air showers. The temporal resolution is on the order of 12 hours. CTA will most likely be constructed on an arid high plateau with mostly clear atmospheric conditions and low cloud cover. In such an environment, the atmospheric state variables tend not to change too much in the course of one night. Therefore, the resolution of the airport balloon data is sufficient. CTA cannot be constructed too close to cities due to air and light pollution. This also means the site will be far away from any airports, and the validity of atmospheric data might not be given over too large distances. In these cases, data from numerical weather prediction can be used.

The Global Data Assimilation System (GDAS) is based on forecast data from numerical weather prediction which is supplemented with real-time atmospheric measurements around the globe. This includes weather stations, balloon data and satellite measurements. The GDAS data are modelled on a one degree latitude-longitude grid ($360^\circ \times 180^\circ$), with a temporal resolution of three hours. GDAS provides 23 pressure levels, i.e. 23 different altitudes, from 1000 hPa (more or less sea level) to 20 hPa (around 26 km). Lateral homogeneity of the atmospheric variables across several kilometres can be assumed on arid high plateaus. The validity of GDAS data in such conditions was previously studied for the site of the Pierre Auger Observatory in Argentina. The agreement with ground-based weather stations and on-site meteorological radiosonde launches is very good for the state variables of the atmosphere [3], as well as the wind [4].

1.1. Validity of the GDAS model at the Namibian site

For the four aforementioned sites, GDAS data were extracted for 2009 and 2010 from weekly data files available through the Real-time Environmental Applications and Display sYstem (READY) website [5]. For the Namibian site, the GDAS data were compared to radiosonde launches performed twice daily at the Windhoek Hosea Kutako International Airport, about 150 km away from the extracted GDAS point. The difference was found to be about 1–2 K in temperature, 2 hPa in pressure at all altitudes. The water vapour pressure differs by about 1 hPa in the lowest 3 km above ground. These differences are expected across distances of more than 100 km. It has to be mentioned, that the Windhoek airport data is used in the assimilation process of the GDAS data, so both datasets are not independent.

1.2. Estimate of cloud cover and wind speed at ground using the GDAS model

Two of the most important requirements related to weather conditions are the cloud cover and the wind speed at ground level. The fraction of clear nights has to be as high as possible, typically a cloud cover lower than 20% during more than 80% of the CTA data-taking. Wind speed affects also operation efficiency. Wind speeds above 8 m/s may impact the quality of the observations and at speeds above 14 m/s no measurements should be performed [6]. In Figure 1, left panel, the distribution of cloud cover for the four sites in 2010 is shown. The two Argentinian sites present the lowest numbers of clear sky configurations whereas the Chilean site seems the best one. In the right panel of Figure 1, wind speed distributions are plotted for the year 2010. The Namibian and the southern Argentinian site present the lowest values, with no values beyond the operational limit of 14 m/s. In conclusion, combining the two main requirements listed previously, the site based in Namibia seems the best one to install the future CTA for the Southern Hemisphere. In Figure 2, left panel, the monthly distribution of clear ($\leq 20\%$) and cloudy skies ($\geq 80\%$) in 2010 is shown for the Namibian site. The sky is almost completely clear

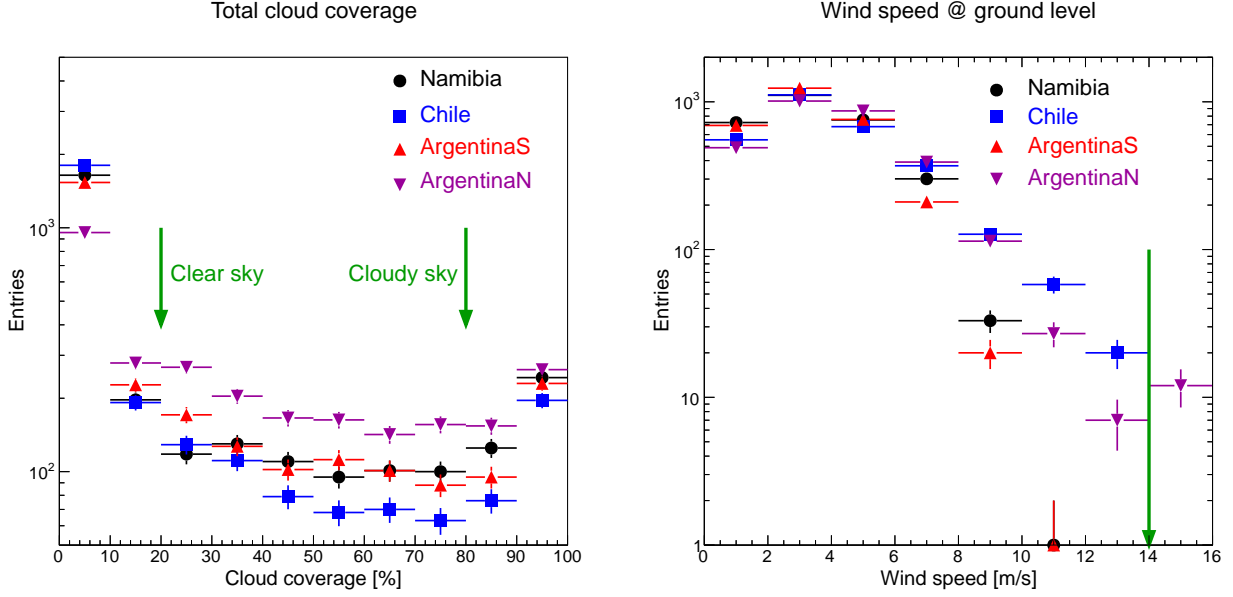


Figure 1. Cloud cover (left) and wind speed (right) distributions for the four sites in 2010 using the GDAS model. An estimation of each value is provided every 3 hours. ArgentinaN and ArgentinaS correspond to the northern and southern sites, respectively. The arrow drawn for the wind speed distributions represent the speed where no observations are performed.

during the entire summer (June to August). Compared to the other sites studied previously, Namibia presents the highest number of hours of clear sky.

2. Origin of air masses in Namibia using the air-modelling program HYSPLIT

Another important part before deciding where to install the telescope array is to know the origins of the air masses above the telescopes during data-taking. A study done by the Pierre Auger Collaboration has shown that air masses coming more directly from the oceans without travelling over land for too long had a lower aerosol concentration when they were passing above the array [4]. This conclusion leads to claim that sites close to the coasts should have a clearer sky in terms of aerosol concentration. Aerosols are the most variable term affecting the photon propagation in the atmosphere. It depends mostly on the local environment and long-range transportation.

Different air models have been developed to study air mass relationships between two regions. Among them, the *HYbrid Single-Particle Lagrangian Integrated Trajectory* model, or HYSPLIT [7, 8], is a commonly used air-modelling program in atmospheric sciences that can calculate air mass displacements from one region to another. The HYSPLIT model, developed by the Air Resources Laboratory, NOAA (National Oceanic and Atmospheric Administration) [5], computes simple trajectories to complex dispersion and deposition simulations using either puff or particle approaches with a Lagrangian framework. A backward trajectory is computed over 48 hours every hour, throughout the year 2010. The start altitude is fixed at 500 m above ground level. In Figure 2, right panel, the distribution of the backward trajectories in 2010 is displayed for the Namibian site. Air masses come mainly from the West, after having just a few hours above continental areas. Following the conclusion presented in [4], aerosol component should be optimised for such telescope observations. Lidar measurements performed at the H.E.S.S. site could confirm these observations [9].

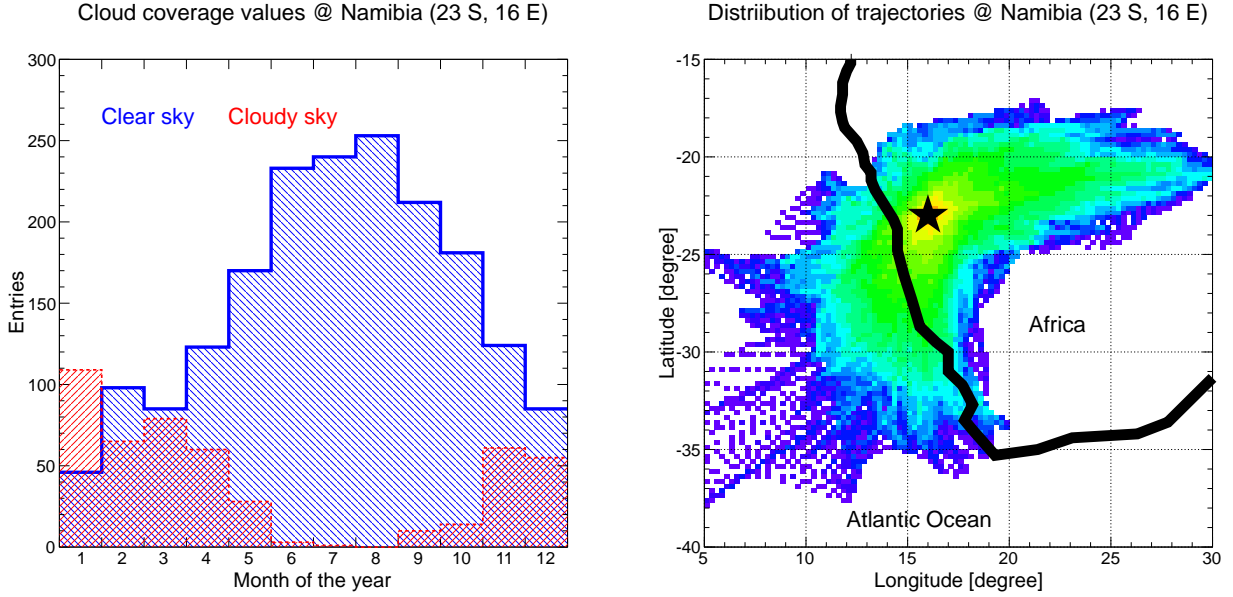


Figure 2. Atmospheric considerations for the Namibian site. On the left, monthly distribution of clear skies ($\leq 20\%$, continuous line) and cloudy skies ($\geq 80\%$, dotted line) for the Namibian site using the GDAS model. On the right, distribution of backward trajectories of air masses in 2010 using HYSPLIT. The black star and the black line represent the Namibian site location and the South-West African coast, respectively.

3. Conclusion

CTA will be the next generation of imaging atmospheric Cherenkov telescopes. Using atmospheric global models, this work presents the atmospheric conditions for the main candidates for the experiment in the Southern Hemisphere. Regarding requirements on wind speed at ground or cloud cover, the site close to the H.E.S.S. site in Namibia seems the best location. Backward trajectories of air masses passing through the Namibian site confirm this conclusion. Weather stations built by the CTA Consortium, the so-called ATMOSCOPES, can be used to verify these conclusions from global models.

Acknowledgments

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